Star History Lecture

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The Roman bridge-builder: some aspects of his work

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To judge from the literature on Roman engineering, there was a time when the history of bridge building was a prominent theme closely associated with a parallel and equally well-developed interest in Roman roads. Recently, as a result of a variety of new approaches to archaeological, technical and social themes, the emphasis has moved to aspects of hydraulic engineering and, in particular, problems of water power and water supply. Of course, fashions in engineering history, Roman or later, are bound to change from time to time. That is understandable and nothing new. On the other hand, any overall view of Roman civil engineering needs to integrate the various approaches, especially in so far as they affect one another. Bridge building, after all, is bridge building, whether the structures are for roads or aqueducts and, in this lecture, both functions will be considered.

However, before turning to engineering historical matters, it is important to notice, even briefly, a few points about method that are fundamental to comprehending the ancient past and especially its engineering. It is noticeable how frequently engineers who write history are disposed to imagine that any failure to comprehend early engineering is essentially a failure of modern intelligence. Too rarely is it realised that the real problem is a failure of the ancient evidence to reach the minimum level that comprehension and conclusions require. Nor, contrary to a number of recent exercises, is it a foregone conclusion that resort to modern analytical devices and computation is a means of making good gaps and faults in the evidence or illuminating problems of interpretation. What is more, and what is often worse, is that retrospective analysis of all manner of ancient technologies – machines, ships or metallurgical processes, never mind structures – can often become a debate about the validity of analytical methods *per se* and the historical issues are lost sight of. When it comes to trying to comprehend the Roman engineer's thoughts and ideas about design and construction, one must never forget that the evidence from the structures themselves is no substitute for the written word – and that commodity is always rare and frequently ambiguous.

A second proviso is a function of survival. Those Roman structures on which we are encouraged to base our historical and structural interpretations are not necessarily typical – and they might have come down to us for particular reasons. Perhaps they were well constructed of particularly durable materials in good conditions; they may have occupied an especially strategic location which encouraged sustained and thorough maintenance over the centuries; or, quite the opposite, survival may have been ensured by isolation. Some of the gems of Roman bridge-building, however small in size or infrequently reported, are in the middle of nowhere and they survive – often unspoiled and original – simply because they have hardly been used at all.

Thirdly, it is important, in these historical assessments, to remember that any bridge which, in 2000 years, has been used by traffic, abused by armies, and misused by the ignorant, will surely have had to be maintained and repaired, altered and rebuilt – in some cases very considerably. How much of a surviving Roman bridge is actually Roman can often be a very good question; one is reminded of what purports to be an original W. G. Grace cricket bat with its two new blades and three new handles.

Road bridges were built by the Roman Government. Their function, above all, was to meet the needs of military transport and the administration of an empire. It is true that they were used for commerce as well but that, on the whole, was not their purpose. The freight traffic of the Roman world was moved far more efficiently by boat, on the sea and rivers and, here and there, on canals. Bridges for aqueducts, on the other hand, were built by towns and cities; the Imperial Government was not involved usually, although famous names are associated with the sponsorship of many aqueducts. Privately-built bridges appear to have been undertaken but rarely, the only certain example being in the mountains above Aosta. Il Pondel (as it is called) is a curious structure, apparently built as an aqueduct bridge at the outset, quaintly modified during its life to serve as a fortification, and then becoming a road bridge – a function that it continues to meet, albeit for a very narrow track. Unusually, it can be dated with precision, to the year 3BC according to an inscription that survives above the keystone.

Even though we have a record of bridges being built by the Assyrians, Etruscans and Greeks, it is with the Romans that bridge building first became a widely practised aspect of civil engineering, so fundamental was its contribution to the management of an empire and the life of its towns and cities. Moreover, bridge building was an activity that typifies those three features of Roman engineering which exemplify its character and even anticipate modern times – arcuate construction, the use of concrete, and the concept of public works. Let us now see if something of the nature of Roman bridge-building can be portrayed by considering the sequence of building a bridge, the choices which had to be made, and the techniques adopted.

At the outset, some surveying might be necessary. In the case of aqueduct bridges, significant requirements had to be met because these structures not only had to carry their water channels at the appropriate slope, or on the level, but it was necessary also to match them with sufficient accuracy to the falling gradient of the channels upstream and down. Moreover, substantial and last-minute adjustments to levels in the manner that might be allowable – however infrequently required – with a road was

Fig 1. One arch spanning 20m survives in the bridge at Narni on the Via Flaminia

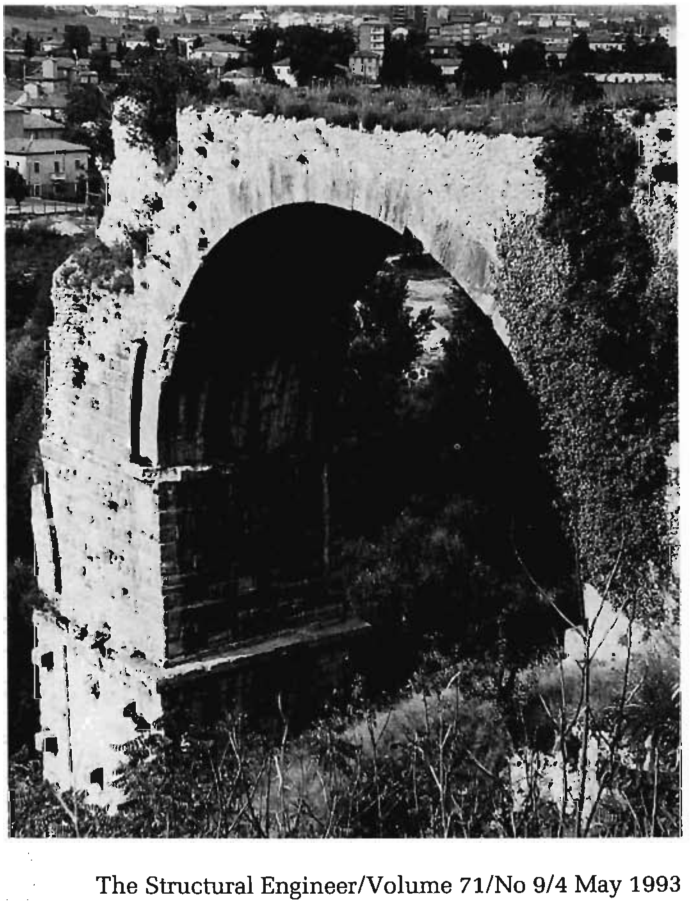


Fig 2. The half-mile-long bridge across the Guadiana at Mérida, often damaged by the river and wars and frequently rebuilt therefore

Fig 4. The Pont du Gard, an aqueduct bridge, possibly Augustan, and notable for being very largely original

not necessarily a practical expedient in the case of an aqueduct. However, aqueduct surveying is a complex subject, appropriate to mention here but too involved for consideration in its own right.

How much surveying went into the setting-out of a typical road bridge is impossible to determine. Surveyors' marks on one pier of the Narni Bridge (Fig 1) appear to record distances measured from the pier, but whether they refer to inter-pier distances or route mileage is unknown. It is also worth noticing that, in the *Corpus Agrimensorum*, is a work entitled *Fluminis Varatio* which includes a description of a geometrical technique for determining the width of a river[1]. One can imagine how such a method might have been used to establish certain basic features of a bridge's construction, but we do not know that it was ever done.

Surveying the layout of a bridge may not have been an especially significant procedure; examining foundation conditions probably was because experience would have told the Roman engineer what the historical record tells us – that ancient bridges were most vulnerable in their foundations and that was where failure was most likely to be initiated. Had the typical Roman bridge been built on dry land, the generally massive construction would have been more than adequate to resist everything except, perhaps, military action or seismic activity. And this contrast between the fragility of the piers below and the security of the arches, trusses or girders above is evident in bridge building right through to the 18th century.

One solution to the problem was to dispense with piers altogether. The bridge of boats is an idea at least as old as Xerxes' crossing of the Struma, while the best-known Roman example is depicted in a finely preserved mosaic in Ostia. It shows the boat bridge at Arles, the only Roman bridge across the Rhône below Lyon and so compactly built that it prevented navigation further up-river by seagoing vessels. Vestiges of the bridge's abutments survive.

Alternatively, bridge foundations might be built well above water level, at least normal water-level (the situation that might prevail in the bridging of a gorge, for example), and a number of examples are known. The concomitant, of course, was often the need for a considerable span.

Another recourse to assist foundation construction was to confine work to the dry season, so that as many piers as possible were easily accessible.

Fig 3. This part of the bridge at Salamanca is still essentially Roman; the remainder, to the south, was considerably restored in 1677

It must have been a technique of considerable advantage at such places as Mérida, across the Guadiana (Fig 2), or Salamanca, across the Tormes (Fig 3), provided that work proceeded fast enough, or in well-judged phases, so that the huge floods that threaten every year did not wash out unfinished or unprotected construction.

We have little evidence that rivers were ever diverted in order to make foundations accessible. It has been conjectured that some sort of diversion was achieved by Trajan's engineers on the Danube – although the evidence and the arguments on which it is based are not convincing – and an interesting variation has been suggested for the Pont du Gard (Fig 4)[2]. Under this aqueduct bridge, the rocky bed of the river appears – one can put it no stronger – to have been artificially deepened to confine the flow, at least when the Gard was running normally. There is, moreover, some evidence that Roman engineers occasionally resorted to rudimentary methods of diverting, or at least containing, rivers in order to build dams, and it is possible that comparable techniques were adopted for bridge building.

Ultimtely, of course, *the* bridge-building problem arose in deep and wide perennial rivers such as the Thames, the Rhine or the Rhône. Temporary military bridges are a type to be included here because one of the most celebrated of all Roman bridges was the one thrown, as they say, across the Rhine by Julius Caesar in an operation described by him in *De Bello Gallico*[3]. This structure and others comparably large and strategic must have been routine for legionary engineers. What the technique required, essentially, was the driving of sets of vertical and angled piles to create across a river a series of parallel trestles which were then spanned one to the next by beams and ballustrades. With no great difficulty, presumably, the piles of such a bridge were readily loosened and floated away for further use as the army moved on.

Permanent all-wooden bridges were undoubtedly resorted to as well, even though their inability to endure has left us little evidence of their existence and even less as to how they were constructed. One supposes that they were common in northern Europe and, in fact, modern opinion tends to the view that, along with other Roman bridges in Britain, the first London Bridge was entirely of wood. Interestingly enough, one can make a case for sequences of bridges along the Tyrrhenian cost of Italy also being made of wood[4].

Pile driving was fundamental to Roman bridge-building because, even when the temporary piers of a military bridge or the permanent piers of a wooden one were not the overriding issue, piles were needed to create cofferdams in which to establish the base foundation for masonry construction above. The history of pile driving, its machinery and techniques, is not yet a well-researched field and what is well understood dates from periods well after the Roman. However, given the crudity of even early modern pile-driving (never mind that of the Middle Ages), and assuming that Roman engineers were no better equipped, we can reasonably extrapolate back from the later evidence. Early pile-driving utilised a barge, or two moored side-by-side, from which the piles were driven by brute force, gangs of workmen manually raising a weight – by ropes if a heavy impact was intended – which fell repeatedly on to the pile. Hard, tedious and slow it must have been, but we must never underestimate the ancients' capacity to achieve results by the massive application of brute and labour-intensive force.

Cofferdams were formed of piles driven close together, and there is some evidence that they were interconnected in certain circumstances, either as an aid to positioning, or to improve watertightness, or both. At Trier, archaeological evidence suggests a double row of piles with clay packed between to seal the cofferdam[5]. Cofferdams must have been drained and maintained dry with relatively simple and compact machines such as the chain-

Fig 5. The piers of the Ponte Leproso at Benevento are protected by a platform; the superstructure is a mixture of workmanship

Fig 6. In this downstream view, many and various styles of construction are visible in the piers of the Córdoba Bridge

of-pots or bucket devices. Anything more elaborate would have been too bulky when one remembers how closely pier construction had to be fitted to the cofferdam wall. It was, after all, difficult enough to drive piles in the first place, never mind pull them afterwards, so that leaving them in place around the finished pier to act as 'starlings' was expedient . That such protection was worthwhile is clear from the regularity with which, over the centuries, bridge piers have required their starlings to be reconstructed – so much so that, in some cases, veritable islands have been created.

If good bedrock could not be found within the completed cofferdam, a foundation of piles would be driven. Here and there the archaeological record is able to indicate something of what could be achieved. Great arrays of piles 2-3m long – as much as 8m occasionally – and up to 50cm in diameter have been discovered in the foundations of some major Roman bridges. Even a minor bridge such as the one at Aldwincle in Northamptonshire featured 5m piles with a cross-section of 50cm x 50cm. Iron tips of some size appear to have been a standard accessory. As Villard d'Honnecourt shows us in a medieval drawing, once driven the piles were cut to a level and a grillage was laid as a basis for pier construction, and doubtless the Roman technique was the same.

The typical masonry pier comprised an outer wall of cut masonry, the blocks often bound together with iron clamps set in lead. Some bridge piers consisted of cut masonry throughout; in other cases, rubble concrete was placed within the masonry outer wall. In itself either technique could be relied on to give very strong and stable support for the road structure above, as indeed was still the case 2000 years later when the same principles of masonry bridge-building continued to prevail. However, against the ravages of rivers in full spate the typical Roman bridge pier was often found to have insufficient strength. The reasons, in proportions which varied from one bridge to another, were inadequate underwater construction and very defective hydraulic performance; in short, the risk was of being undermined. Any number of Roman bridges featured piers of totally adequate dimensions as such but, being furnished with cut-waters only on the upstream side, the downstream face being built flat, their susceptibility to erosion and scour was considerable and sometimes fatal. Curiously enough, there are exceptions. The first bridge at Chesters[6] had cut-waters up-and downstream and there is evidence from elsewhere that doubly pointed cut-waters were utilised occasionally.

Some Roman bridges featured platforms, or aprons, which surrounded the feet of the piers and usually covered the whole of the riverbed in the vicinity of the bridge. Such platforms may be original (which appears to be the case at Piercebridge on the River Tees) or, equally, they may be remedial, which is probably true of the bridges at Benevento (Fig 5) and Cordoba (Fig 6). Either way, here was a measure designed to resist scour and erosion. Also, it is noticeable throughout Europe that medieval weirs, built for a variety of primary purposes, were often located *downstream* of Roman bridges, and very probably the intention was to allow the bridges' piers the security of still water. It is, moreover, the case that the cut-waters we see today on many Roman bridges, up-and downstream, are not Roman in origin but are later additions or remodellings. My earlier question about how Roman is a Roman bridge is nowhere more pertinent than in these matters of piers, starlings and cut-waters.

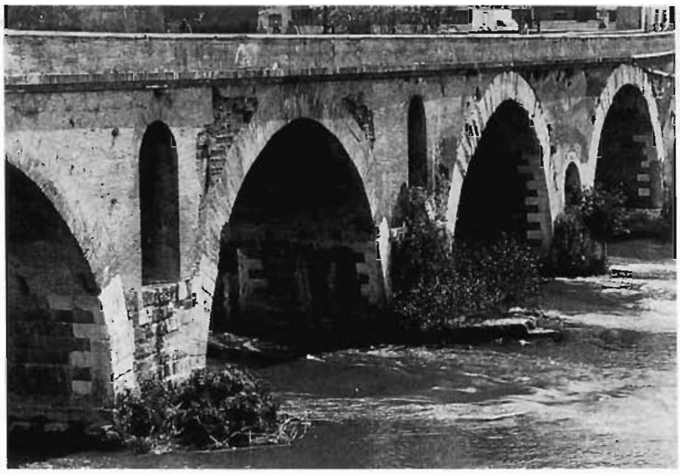


Fig 7. The large tunnels in the spandrels of the Pons Milvius (109BC) were probably intended to assist the passage of the Tiber in flood

Fig 8. The Pons Fabricius (62BC), another Tiber bridge with provision to cope with deep water by means of a central flood-relief tunnel

Fig 9. A downstream view of the Alcántara bridge, 185m long and standing some 50m high in its tallest pier

Fig 10. The Alcoñetar Bridge whose ruins were not only restored recently but, in addition, were moved from their original location as the waters of a new reservoir began to rise

Fig 12. The Pont Julien near Apt in Provence, as thin at the crown as any Roman arch anywhere

One other feature of Roman bridges may indicate a concern about waterflows: it is the provision of tunnels in the spandrels. Conceivably, this was a device to ease the problems of construction and lighten the structure's weight. But equally, these tunnels would have acted as flood arches and such may have been the intention (Figs 7 and 8). Interestingly, however, what was usual in the early days became less commonly practised later on, and how far this might reflect the evolution of other aspects of bridge design is at the moment unclear.

In its superstructure, the traditional Roman masonry bridge used the full semicircular arch. A bridge such as Salamanca (Fig 3) shows the style to perfection. Fundamental to modern interpretations of this form is the belief that the combination of semicircular arches and heavy piers allowed construction to proceed arch-by-arch from one end to the other or both ends towards the middle without risk of collapse at any stage. And, indeed, this may be a proper conclusion. Moreover, it is interesting to notice that the fine and famous Alcántara Bridge (Fig 9) in western Spain may, in an unexpected way, confirm this view. Because of its strategic importance, the Alcántara Bridge has, over the centuries, frequently been breached in one or other of its spans – and yet it has never failed, which indicates that even so relatively tall and slender a structure would stand securely even when denied its structural integrity: in which case the low multispan bridge was hardly likely to have been a bigger problem. Indeed, it is not fanciful to postulate, given the Alcántara evidence, that even high bridges were built from end-to-end or ends-to-middle, one span at a time, rather than integrally from foundations upwards with all the arches, or at least their falsework, being completed simultaneously. Variations in the dates and styles of successive piers in the Narni Bridge (Fig 1) also seem more consistent with a constructional sequence from end-to-end rather than one proceeding from bottom-to-top. Just as significant, too, is the fact that, in modern times, one single, large span of the Narni Bridge has survived alone, like a triumphal arch, and other ruined Roman bridges exhibit structural stability in one or a pair of surviving arches, even though all else has fallen.

Contrary to a frequently encountered opinion, the Roman bridge-builder was not restricted to semicircular arches, not even in masonry and certainly not in wood. The remains of the Roman bridge in Narbonne, nowadays all but lost between later bridges and under modern buildings, indicates the use of segmental arches, as does the recently relocated Alcoñetar Bridge (Fig 10) in Spain[7].

Fig 11. The Ponte sul Lys on the road to Aosta with a span of 37m

Precisely how bridge arches were formed is not always clear and, in any case, methods no doubt varied. All the same, many road and aqueduct bridges display traces of the slots and projections that were obviously used to support wooden scaffolding and falsework during construction, not to mention subsequently for maintenance and repairs when those were necessary. Such falsework might be built to the full width of the bridge – sufficient, in other words, to support the construction of a complete arch. Voussoir rings might be of masonry, possibly clamped with metal, or brick and tile with infill above of rubble concrete into which, as noted above, flood relief arches might be incorporated using further falsework. In the Pont du Gard an interesting variation seems to have been preferred. The voussoir rings apparently were erected one after another, using the same piece of centering in successive positions, three or four, across the width of the bridge at each of its three levels. In the large and single span of the Ponte sul Lys at Pont-St-Martin (Fig 11), east of Aosta, the same technique appears to have been used, although here the difficulty of distinguishing Roman work from medieval is considerable. In the medieval Pont d'Avignon, there is further evidence of the same procedure..

Masonry piers were not necessarily spanned with voussoirs of masonry, brick or tile. Where it was economic and expedient to do so, wood was used to construct a superstructure, a deck of beams where spans were suitably short but, more interestingly, trussed arches for longer spans. It is conventional, and convincing, to reconstruct, in both models and the mind's eye, the bridges of Roman Britain as utilising wooden beams or arches while, in the case of Apollodorus' bridge over the Danube (built for Trajan in AD 105/106), we can be sure of the use of wooden trussed arches from the unique evidence on Trajan's Column[8]. Attempts to decide the constructional details of such arches and how they might have been assembled are essentially futile; it is the general principle of Trajan's bridge which is so important, particularly when it is remembered that this was a bridge of considerable length, perhaps 3500 ft, across a big river into whose bed some 20 piers in masonry were sunk. Fragments of them discovered in modern times verify aspects of the contemporary descriptions. Dio Cassius says the structure had spans of 170ft and piers 60ft wide, in which case arched trusses in wood do seem appropriate. Apollodorus' familiarity with this style of construction, and his confidence in it, possibly led to its being used elsewhere, and the most frequently claimed example is Iberian. The emperor Trajan was responsible for a substantial rebuilding of roads in Spain, including the Via de la Plata from Astorga to Mérida. The bridge of Alcoñetar (Fig 10), which carried that road over the Tagus, is conceivably by Apollodorus, or at least reflects his influence. Certainly, the bridge's proportions are broadly those of the Danube bridge, and the ruins indicate the use of segmental rather than semicircular arches, but almost certainly in masonry rather than wood.

Various details of Roman bridge-building having been referred to, it will be useful now to generalise with regard to questions of types and styles and their distribution. The masonry-piered bridge was adapted to suit valley profiles, as one would expect. Wide and flat river valleys were crossed with long multispanned structures using semicircular arches. The choice between wood and masonry for the superstructure would have depended on the economics of availability and skill, as well as considerations of span length

Fig 13. The Ponte di Tiberio at the end of the Via Flaminia in Rimini, often damaged, as frequently repaired, and still in use

Fig 14. A downstream view of the bridge at Sommières (only seven arches of the original bridge still span the river, the others having become *caves* and garages in the town to the right of the picture)

in the conditions. For example, it seems clear that bridges across rivers as wide as the Danube or Rhine featured wooden arches and decks. In deep and broad valleys, fewer, but larger, spans were often the style, as at Alcántara or Narni for roads or the Pont du Gard for an aqueduct. If a deep valley was also narrow (in short, a gorge), a masonry bridge with one suitably large span might have been the solution; Vulci and Ascoli Piceno are examples. A fourth type was what, in the Middle Ages, was sometimes known as a 'devil's bridge' – a high, single arch to clear a river in one go but with steeply graded approaches if the banks were at a relatively low level (Fig 12). Bridges wholly of wood were either military structures, quickly built and just as quickly dismantled, or else they were used where economy and resources favoured nothing else – in northern Gaul or Britain, say.

Particular routes often display a characteristic structural style for which we have evidence or can make the appropriate inference. Along the Via Flaminia there was a sequence of important masonry bridges of which the Ponte d'Augusto at Narni and the Ponte di Tiberio at Rimini (Fig 13) are the significant, but not the only, surviving examples. On the other hand, although we know of roads along the western coast of Italy, their crossing points of major rivers – the Arno, say, or the Garigliano – have left us no bridge remains. As noted earlier, it is probable that, over those wide and deep alluvial rivers, it was wooden bridges, long since washed away or burned down, which predominated, a proposition borne out by recent work at Minturnae[4].

Until the Augustan period, wooden bridges also predominated along the Via Domitia in southern Gaul. Their replacements were well-built masonry structures, some of which survive, either intact and in use (e.g. at Narbonne and Sommières (Fig 14) or else as intriguing and impressive remains like those of the Pont d'Ambroix at Gallargues (Fig 15). Less well-known are the numerous places along the western side of the River Rhône where the northbound road had to cross such tributaries as the Escoutay, Ardèche and Doux. Above la Voulte-sur-Rhône, one can still admire the abutments of a mighty bridge which once spanned the Eyrieux with a single arch of some 30m.

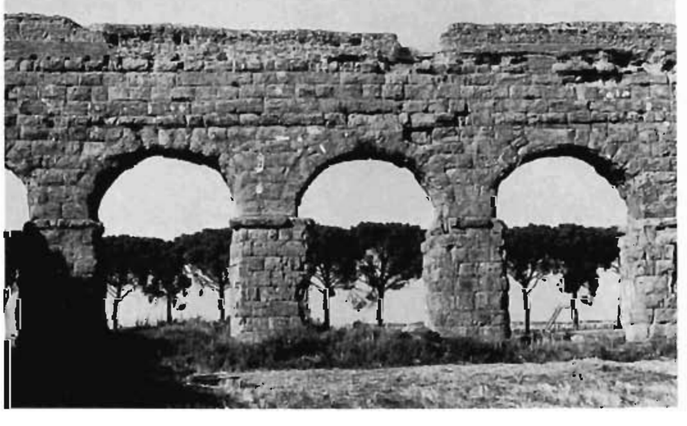
Aqueduct bridges were a special case of bridge building, and this led to distinctive styles tailored to purpose. The essential point here, as we have seen, was that these bridges, in addition to carrying the rather trivial loading of a water channel and its contents, had to maintain a suitable hydraulic gradient as well – and, not infrequently, the latter was essentially the main purpose. It is this requirement which imparts such a striking appearance to the beautiful bridge in Segovia (Fig 16) with its tall, slender piers closely spaced in a structure much narrower than any road bridge could have been, or the majestic arcades that stride across the Campagna to Rome (Fig 17). So massive an edifice as the Pont du Gard merely maintains the slope of a not very large aqueduct. One can observe here, incidentally, how much more susceptible were such tall, narrow structures to lateral displacement and, in fact, in some aqueduct bridges the Roman engineer provided an element of buttressing; Fréjus and Mérida are examples and the same technique appears in the upper part of the Alcántara road bridge.

How Roman bridges, and other structures, were designed – and the term 'design' must be used with due care and caution – remains very obscure so far as detail is concerned, even though, in broad terms, one or two aspects of what might have been involved can be postulated. Simultaneously, we can reject those recent inquiries, based firmly on modern theory, hindsight and wishful thinking, which have encouraged some modern writers to

Fig 15. One arch of the Pont d'Ambroix refuses to yield to the Vidourle

Fig 16. One of the finest of all Roman structures, the 1st century AD aqueduct bridge which dominates Segovia

Fig 17. The Aqua Claudia, of large masonry blocks, carries on top the Aqua Anio Novus, of brick, across the Campagna



attribute to ancient – and, for that matter, medieval – engineers a ridiculously advanced understanding of design concepts, techniques and calculation. All the same, some process of structural design, however rudimentary, must have been employed; it is perfectly absurd to imagine that, one morning, gangs of workmen with materials and equipment turned up at a site and simply got busy. There must have been a 'design' of some sort to work to. And indeed the ancient sources do indicate something of the nature of the rules of proportion, and the readiness to *rely* on proportion, that was fundamental to ancient design. For later periods, the forms of the structural design rules by then in use – and no less interesting their variety – are prominent in a number of bridge designers' work. From as late as the 18th century we can study the rules used by John Smeaton to relate arch thickness, span and the degrees of arc to the width of pier and notice, moreover, that he more than once changed his mind. Overall, it is probably not fanciful to extrapolate bridge-building rules of this type, or some anticipation of them, however simple, back through the Middle Ages to the Roman epoch.

If Roman engineers had learnt to proportion a bridge on the basis of some assumed, or derived, relationship between (shall we say) arch span, voussoir thickness, pier width and possibly rise (and a similarly appropriate group of parameters for a truss), one might suppose that the statistical analysis of sufficient bridges ought to reveal the rule, or rules, used. The problem, however, is that, even if a rule that met all the requirements could be established, it would by no means follow that it was *the* rule. It is rather like trying to recover the clues to a crossword from the finished puzzle: it is easy to arrive at an answer, but impossible to know whether it is correct. Similarly, we should be cautious in considering the claim by J. B. Ward-Perkins that the Pont du Gard's design is based on the ratios 4:3:1:6 for the proportions of the central, lateral and upper arches and the overall height. In fact, such a 'design' is unconvincing because, in reality, the proportions claimed are very approximate, to the nearest whole number when measured against the bridge itself. For design proportions of this sort to be really persuasive, they need to be exact.

Let me now add a fourth qualification to the three outlined at the beginning. Much that is written about Roman engineering – and probably because, more often than not, the authors are following an established tradition – advances the view, or at least presupposes, that any field of technical activity was essentially an entity throughout the empire. Whether it was mining, irrigation, swordmaking or shipbuilding, it is not acknowledged in many studies that, from place to place in the Roman world, there was probably more than one way of doing things. And, as here discussed, in relation to bridges, some facets of regional variations can be put down to the materials available, to constructional necessities characteristic of certain localities, and to specific structural problems. There are at least a couple of other factors to consider.

How far Roman engineering was derivative from earlier societies, and how far it was indigenously Roman, is a complex matter and overall the balance between the two must have varied greatly with technologies and localities. That Greek influence in building was powerful is well established and, for the early period in Italy, so probably was Etruscan. In northern Europe, it seems clear that traditional techniques and craftsmanship inevitably were adopted from captive peoples. Whether or not bridge building was thus absorbed is impossible to determine, particularly because it was an activity whose extent in the pre-Roman period is, in any case, very uncertain.

Secondly, we ought to notice that some variations in Roman bridge-building techniques may well have been matters of opinion among designers and builders. Conceivably, the differences detectable in arch forms, pier shapes and the size of flood arches were due to the application of theories, novel or routine, of individual engineers or embodied within the expertise of a practising group such as a legion – a 'school of thought', in other words. In reality, it is exceptionally difficult to draw even the outlines of the lives of more than a handful of Roman architects and engineers, never mind scrutinise their opinions and ideas. Moreover, within the ranks of army engineers and their staffs, varying experience and familiarity with particular techniques in different circumstances and places – legions did, after all, move about – might have served to diffuse and distribute practices in a manner that led to a degree of standardisation but might, depending on a legion's travels, have led to quite the opposite. It is not a matter that has received much study.

Overall, these observations on the nature of Roman engineering design and associated concepts and influences allow a final thought.

It is customary, and not unnatural, to present developments in Roman bridge-building, and indeed other branches of structures, as assuming that the same sequence occurred everywhere at the same time. This leads some writers to date structures and place them within a progression of developments and events according to how their features fit the generalised chronology. In fact, it might not be so straighforward, if only in the sense that, if the take-up of techniques from one place to another was subject to a timelag, the chronology would be displaced, so to speak. And, in any case, the dating of a sequence of bridges can *appear* incompatible even when the opposite is known to be the case. Augustus undertook the rebuilding of the bridges along the Via Flaminia in 27BC. The fact that the new set of bridges dates from the one period does not preclude a great variety in methods of construction brought about not least by the expediency of rebuilding existing structures. Reconstruction of older edifices is capable of undermining dating as tboroughly as any other single factor. Questions of style, technique and chronology are easy to propose but much less easy to resolve, and this shows how far we are from a definitive account of Roman bridge-building.

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